AquaMarine

Distributed Real-time Oil Spill Detection and Protection System

Team Name

Wings

Team Member:

Shibiao Xu

Junjie Li

Zhongjie Wang

Lei Yan

Mentor:

Li Guo

Beijing University of Posts and Telecommunications

1. Abstract

Marine oil pollution has become an increasingly serious global environmental problem. Once there is an oil spill, efforts then have to be made to contain the damage and minimize the impact to the environment, usually a very costly operation.

In this paper, a detailed description of our AquaMarine system is given, whose main application is to detect marine oil spill. The system implements distributed solution, meanwhile adopts multipoint monitoring on oil spill in different sea areas using our specially designed buoys which are capable of collecting relevant data as well as transmitting real-time information back to the processing center onshore where data is analyzed and processed, then available information will be released to corresponding users.

2. Executive Summary

The ocean, beautiful and spectacular, has always been regarded as cradle of human life, regulator of the climate, as well as treasure house of natural resources. The ocean itself has great ability of transportation, dilution, diffusion, oxygenation, deoxidization and degradation and other purification capacity towards various pollutants. But that is not to say, it can solve any pollution problem all by itself. When the toxic and harmful substance received exceeds the ocean's own self-purification capacity, pollution occurs. Among various kinds of pollution, marine oil pollution, known as "super killer", is gaining increasingly great attention all over the world.

Through our field research on the relevant information we find that，at present, there still lacks an effective real-time monitoring system which ensure rapid reaction right after oil spill takes place and the accuracy of existing systems with similar application is still far from satisfactory. Once oil spill occurs, whether the accident can be avoided from further extending into large-scale and the possible loss be minimized are directly decided on whether quick detection be taken in the first time with rapid response. And this is how we came up with the idea of our AquaMarine.

Our AquaMarine is a real-time data acquisition and processing system based on the belief that it will do everything possible for immediate discovery on the oil spill accidents and promptly gives out an early-warning to relevant personnel in order to gain the greatest opportunity to minimize the reacting time which is exactly the problem our AquaMarine is going to solve.

AquaMarine mainly consists of three parts, including data acquisition part, data processing part and information releasing part. It is unique of our system to adopt two types of sea buoys with mainly distribution along oil spill accident-prone areas are adopted as the carrier of the data acquisition part, including anchor buoy and floating buoy. Then in the data processing part, eBox-4300 is used to process the raw data and extract effective information from the data collected, providing us with an analysis on whether there is oil spill detected in the current area. Information releasing part, plays the role that publish the early-warning information together with available message we extracted through the most effective way. This ensures the message be conveyed to relevant personnel timely in order that effective emergency measures be taken in the first time to prevent the spread of oil spill.

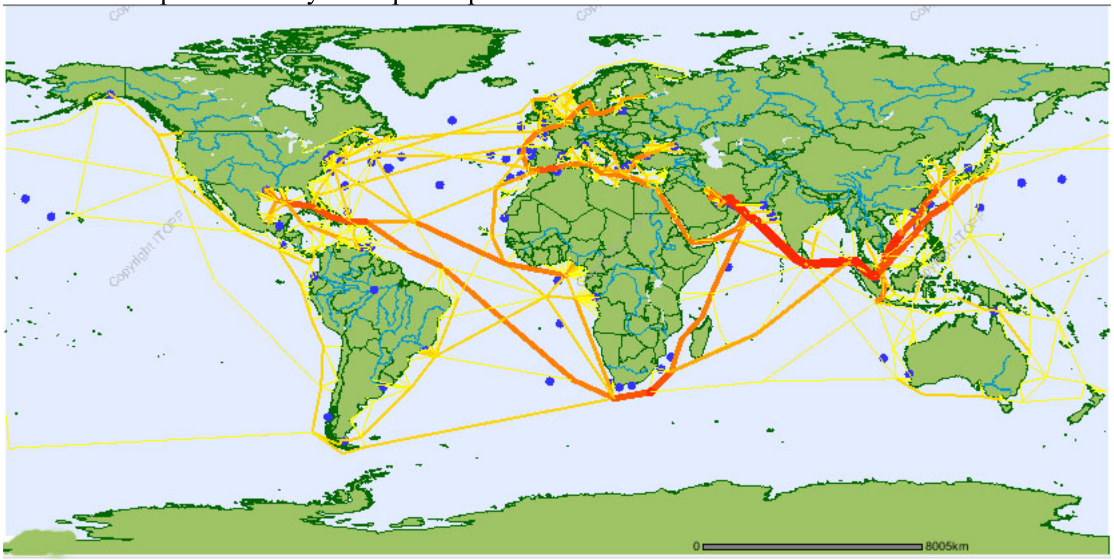
During the practical test, our system has already been able to effectively give out the result on whether there is oil pollution existing, with a success rate up to 96%. On condition that our system be applied in real situation, we fully believe that it will make great contribution to the monitoring and controlling work of oil spill pollution, moreover reduce the bad impact to the environment and finally achieve sustainable environment.

In addition, the implementation of a embedded solution is absolutely necessary because our project tends to work outside where there exists no possibility for a PC solution.

3. Situational Analysis

3.1 Problem Analysis

There are various of operations that may lead to marine oil pollution, mainly including Groundings, Collisions, Hull failures, Loading and discharging, Fire and explosions, and other operations. According to statistics, most of these incidents have concentration in space, forming a number of accident-prone locations (Figure 1). During our research, we also found that under the existing technology conditions it is impossible to eliminate the effect of pollution completely, thus it becomes the most important point for minimizing the bad impact to detect oil spills and carry out rapid response in the least time.



Oil Spill Accident   Oil Transportation Route

Figure 1 The Distribution of Marine Oil Spill Pollution

3.2 Project Analysis

- **Solutions to the Problem:**

Through the problem analysis above, we can easily discover the following characteristics of oil spill. The first one is the concentration of the accident-prone location in space. Second is the low probability of timely detection and rapid response for people onshore. Last but not least, once it spreads, it will be difficult to eliminate their impact on the environment. Our AquaMarine is just designed according to the characteristics mentioned above. The monitoring buoys are distributed according to the spatial concentricity of the place where oil spill accident often occurs. In addition, different sensor groups are used to collect the marine parameters which are then sent to the data processing centre on land by the way of wireless transmission. In the processing center, we also extract the information of the data, analyzing whether there is oil spill or not in real time. Besides, we still use our early warning information publishing system to notify the related personnel timely and effectively. Our aim is to achieve such a result that in which case the oil spill accident happens, related personnel can be notified in the shortest possible time to handle the problem. According to the analysis of the system function, our system is mainly applied in the marine oil spill monitoring no matter it is regional, national or the global.

- **Constraints:**

The real situation of the sea surface has been fully considered during our design process, and AquaMarine can to a certain extent reduce the influence that bad weather brings. However, data acquisition can not be operating accurately under extremely bad condition, even if we get the data under such condition, the accuracy of the processing result could not be reliable at all. Considering these, once extreme terrible weather(like tempest) beyond the range that data acquisition can afford comes, our system will automatically turn into waiting mode ,and stop data collecting .It will not return to normal operation mode until the tempest passes.

- **Project Foundations:**

We introduce some of the ideas from distributed system and meteorological and hydrological monitoring bony in our AquaMarine. While our innovation lies in the structure of the buoy (including anchor buoy and floating buoy) which is equipped with a group of well organized sensors for data acquisition specialized in the oil spill pollution. Besides, we implement our own algorithm to process the raw data after its sending back to the data processing centre onshore and the integration and presentation of the extractive information are also our original ideas. Moreover, in the data acquisition part of the floating buoy, we introduced remote location function for sending accurate coordinates to the buoy, indicating the position of the sampling point. It is also one of our original ideas to integrate the expert system which has been applied widely in various fields into our system, making our system more perfect. Since most of the ideas are first proposed in our system, we have gained a lot of attention from relevant researcher from National Oceanic Administration of China during our survey to the relevant unit.

3.3 User Experience

Users need only basic computer skills, because AquaMarine has adopted the most common web access and a mouse-click graphical mode for operation. Meanwhile web accessing devices such as PC termination, PDA or cell phone are all supported. However, certain knowledge of database and programming skills are needed for administrators to ensure continually improving and maintenance of the system. In our series of test later, there is a statistical testing on how long it takes the users to learn the use of our system. The result (Figure 2) shows that, compared with other systems, our AquaMarine emphasizes more on the humanization and the habit of the users in operating.

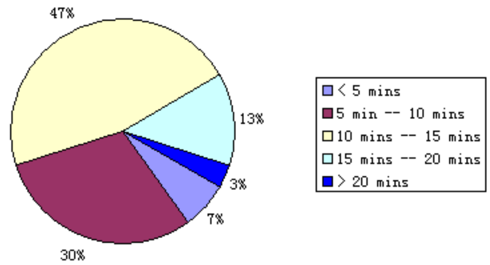


Figure 2 The Beginners' Learning Time Statistics

3.4 Market Analysis

3.4.1 Current Status of Existing System

From our considerable research in relevant fields, we find that, in the current market, there still lacks an effective real-time system aiming at oil spill monitoring. Some of the existing products with similar applications are mostly independent in functions, which are very hard to play systematic effect. In details, we clearly identify major drawbacks with the current systems as follows:

- **Lack of Prediction of Diffusion**

At present, the focus of most existing oil spill monitoring system is just to detect whether there is oil spill occurs. But rarely any system has the ability to give out a scientific prediction of the diffusion trend of the spilled oil, thus the rescue personnel can not ensure a reasonable scheduling even if they have discovered the accident.

- **High Misjudgment Ratio**

The existing monitoring systems are mostly based on spectroscopy technology or remote sensing technology, both of which are vulnerable to the impact of the marine environment, usually causing confusion. For example, solar flare, bright spot and seaweed on the sea surface as well as some of the marine organisms can all become the factors that disturb the equipment based on spectroscopy technology. Meanwhile, due to the low resolution on the ground surface, the probability of misjudgment has been increased to a great extent.

- **High Cost**

Since the most widely used way of oil spill monitoring at present mainly relies on the remote sensing, no matter aerial remote sensing or satellite remote sensing, the high cost can not be ignored. It is indeed difficult for such system to be widely implemented in all the regions with necessary demand but under restricted economic conditions. This may seriously impairs the further development of the underdeveloped areas.

3.4.2 Innovations

- **Application of Distributed System on Monitoring**

Distributed system is adopted in the design of AquaMarine. Large net of sensor monitoring based on multi-point data acquisition is to be put into service in order to realize real-time monitoring on large sea areas. The acquisition point in the net are mainly divided into two types, anchor type and floating type. Anchor type primarily takes charge of data collecting on fixed location, while floating type are able to move to the temporary given point according to the order sent by the control center and implement data acquisition process at the appointed location. This improves the flexibility of the system to a great extent.

- **Application of WSN（Wireless Sensor Network）on Data Transmission**

A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous sensor nodes, which normally constitute a wireless ad-hoc network to cooperatively monitor and collect relevant information of physical or environmental conditions in the covered area then transmit the information to the observer. They can be used to monitor data that would be difficult or expensive to monitor using wired sensors and would remain for many years (monitoring some environmental variables) without the need to replace their power supplies. In this part sensors, perception objects and the observers become the most important factors of the wireless sensor network.

- **Application of Mathematical Modeling on Changing Trend Prediction**

Another point to mention is that except the analysis on whether there is oil spill occurs, we also present a prediction of the spread trend of the spilled oil through mathematical modeling. Users can easily make a full understanding of the current and future situation of the accident, further more realizing better resource scheduling. Before put into practice, the numerical simulation results given by Matlab have shown that the methods presented in the paper are feasible and the simulation result is satisfactory.

- **Application of Expert System**

AquaMarine also comes with an expert system, taking advantage of their knowledge base to give out a reasonable inference according to the data input, which may include suggestion on emergency response and proposals on resource scheduling. The expert system consists of three parts, including Knowledge-Base, Inference Mechanism and Interface. Knowledge-Base is responsible for collecting historical information related to the oil spill incident. Then the information will be categorized in a systematic manner, thus enable the computer to analyze and solve the problem with pertinence. Inference engine is used to make inference in various specialized aspect based on corresponding algorithm or strategy stored in the knowledge-base. Most of the time, it has to give out a feedback according to the problem that proposed by different users. While the main function of interface is to provide relevant input and output of the data.

3.4.3 System Features

Compared with the systems of similar application, our system has the following characteristics.

- **Real-time Performance**

We have paid great attention on the real-time performance of our system. Reasonable time interval is set based on various factors taken into consideration, in order to detect oil spill in the first time and get the real-time information. Right after its acquisition, the data will be sent back to the processing center through wireless communication, where it receives processing and analyzing in real time. Almost at the same time, the processing results can be instantly found released to the users. The concept of real-time performance is strongly emphasized throughout the entire system, where timely and effective feedback information is guaranteed by the coordination among the various parts.

- **Flexibility**

Our system adopts two types of data collection buoys, anchor buoy and floating buoy, each equipped with various sensors according to different conditions. Both the two types can not only collect data at pre-set time intervals in accordance with the procedures but also capable of manually controlled acquisition under unexpected situation. The floating type still has the ability of remote control, in order to realize collection on the designated point. In data transmission part, anchor buoy implements information transmission through self-organized Ad-hoc networks. This on one hand maintains a low cost of delivery, on the other hand increase the flexibility of the system. Once one of these buoys goes wrong, other buoys can have a dynamic regulation on the route, reforming another efficient routing for data transmission.

- **High Accuracy**

Besides the use of general sensors for marine environmental parameters gathering, such as sensors for wind speed, wind direction and temperature collecting, in our data acquisition part, we also put light sensor, infrared camera and viscosity sensor into service, which provide different indicators for oil spill judging. Through this we could build up a comprehensive mechanism with multifactor judging method as a guarantee of high accuracy.

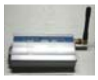
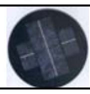
- **High Performance-cost Ratio**

Compared with other systems with similar application, our AquaMarine has got a high performance-cost ratio. We simply implement ordinary sensor modules with low cost for data acquisition, however, some improvements have been made in the way of data acquisition, or in other words, realize a better use of the sensor with developed algorithm. That is to say we get better use of the data to attain more accurate forecast and analysis results on even lower cost.

3.4.4 System Insufficiency

Bad weather and man-made destructions are the main constraints of the entire system as well as all the systems of similar application. Although we have done a lot of work to resist the bad impact brought by the bad weather, such as fix the sensors inside the buoys to provide a relatively stable environment, add emergency strategy during our program design and use high-strength materials as buoy material, still it is impossible to achieve surefire in any operation.

3.5 Cost Analysis

Item	Description	Photo	Price	Amount
eBox-4300	Main Control and Data Processing Device		$200	1
MCU	Data Acquisition Control Unit		$5	5
GPRS	Data Transmission Device		$100	1
Solar Panel	Power Supply Device		$50	1
Storage Battery	Power Storage Device		$20	1
Sensor Group	Collecting Data		$50	1
Total	$445			

According to the items listed in the table, the sink with GPRS transmission module costs $245 each, while the ordinary type without GPRS transmission module charges for $145 each. However, due to our investigation, the price of the ordinary hydro meteorological buoy available in the market is up to tens of thousands of dollars. Therefore, our system also has great advantages in this contrast.

3.6 Research Description

In designing the system, we make a lot of investigation and interviews. Through our field research on relevant information, we find that the effect of oil spills can be far reaching, posing both an environmental and economic threat. Recreational activities, local industry, fisheries, and marine life are among the resources that can be adversely affected by oil spills. Marine oil spill incident, which is known as “marine super killer”, is a serious problem in urgent need of resolving. However, through our interview to the State Oceanic Administration People’s Republic of China, we realized that the existing oil spill monitoring system in practical use is still far from satisfactory. In access to relevant information in the ITOPF(The International Tanker Owners Pollution Federation) [3], we get to know that oil spill pollution has the characteristics that concentration of the accident-prone location in space, low probability of timely detection and rapid response and once it spreads, it will be difficult to eliminate their impact on the environment. According to the characteristics mentioned above, we eventually confirm the system function and the framework. Therefore, after the analysis above, we finally come up with the system scheme of our AquaMarine.

4. Technical Analysis

4.1 Overall Architecture

Our system is mainly divided into three parts: part of data acquisition, part of data processing as well as part of information release, where the exchange of the data flow is an important relation link among the three parts. As shown in the figure below, in the first part, environmental parameters around the sampling points are collected selectively, after simple compression and encoding, then, sent to the data-processing part of the eBox through GPRS or CDMA or by means of satellite communication. When comes to the second part, the data is processed and analyzed by eBox, the results of analysis are then sent to the network server, where users can access through the web to get available data and significant information. The major responsibility of the last part is the release of the extracted information and further suggestion based on the expert system and sometimes the warning signals when necessary.

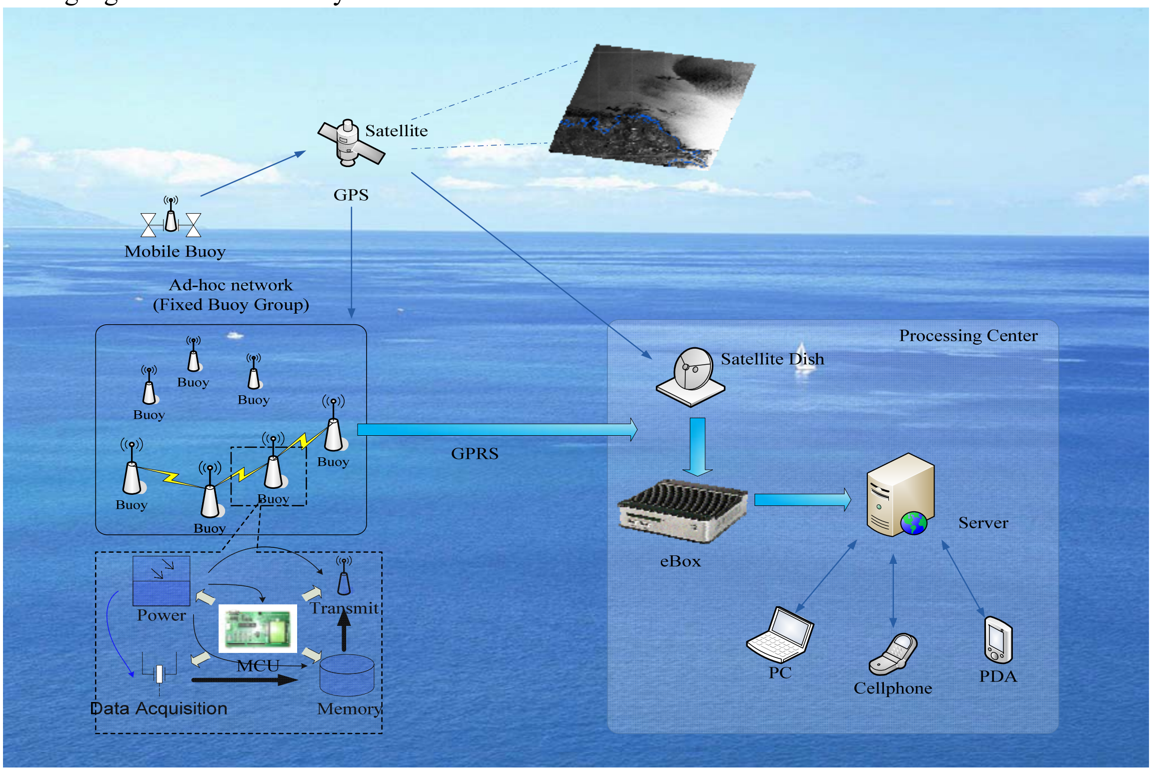


Figure 3 System Architecture

4.1.1 Data Acquisition Part

➤ **Appearance and Structure of the Buoy**

In the data acquisition part, the major operation is collecting environmental parameters such as transmittance, viscosity temperature and wind speed of the sea surface, using a group of well organized sensors, where ocean buoys are adopted as the carrier of the sensors. Different from the existing systems, we firstly develop the buoy into two types, one is the anchor buoy and the other is called floating buoy, both equipped with sensors of different kinds according to corresponding application. The interior of the two types are both divided into four capsules each of which is equipped with sensors groups. When receives data acquisition order, the door of the capsule will open automatically, injecting sea water around the buoy, and then start the data acquisition procedure collecting relevant information from the water in the cabin. According to Principle of connected vessels, the height of liquid surface in and out of the capsule always remains the same. However take the acquisition process inside the cabin have obvious advantages compared with collecting data directly on the sea surface. Firstly, it can avoid the impact of the weather on the light sensor. No matter it is cloudy or sunny outside, it provides a relatively stable testing circumstance inside the cabin. Secondly, it also reduces the effect of the oscillation on the sensors caused by the high waves. Moreover, this implementation makes the whole system more integrated with less risk of damage by external forces.

- **Anchor Buoy**

Anchor buoys are fixed on certain places in accordance with the results given by our algorithm of distribution. They play an important role in collecting the environmental parameters of the surrounding waters and in real time sending them back to the data processing center, where available information of the relevant waters is extracted from the processing result.

Anchor buoy is mainly composed of five modules: sensor acquisition module, data transmitting and receiving module, GPS module, power supply module, and mechanical fastening module.

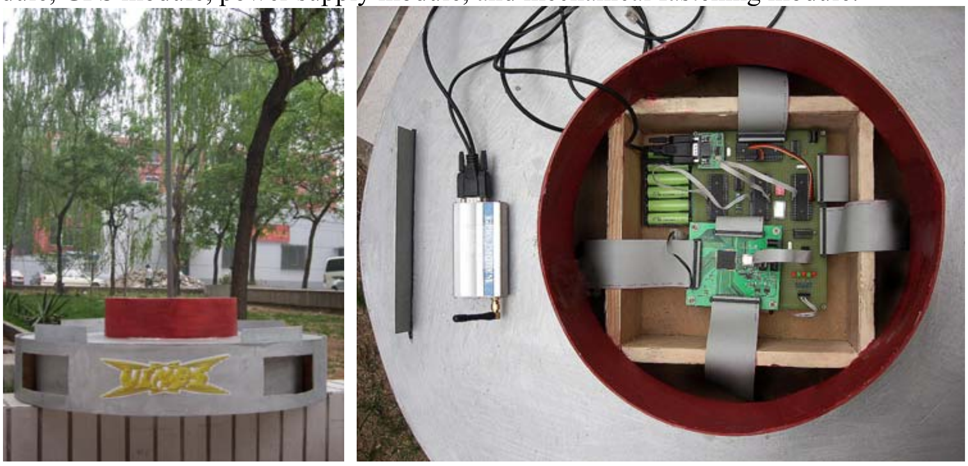


Figure 4 Buoy Image

- **Floating Buoy**

The working principle of the floating buoy is quite similar to the anchor buoy, the major differences are that it adds 4 electric spiral propellers on the end points of two vertical diameters, and it is much more flexible. When the floating buoy receives the order and aimed coordinate from the control center onshore, it will automatically adjusts the algorithm, continuously correcting its own coordinate towards the aimed one through GPS positioning function. When the floating buoy reaches the destination, it will immediately begin collecting data, and then through the GPRS or CDMA or by means of marine satellite communication sending the results back to data processing center.

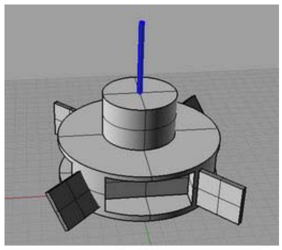


Figure 5 Buoy Model

- **WSN net**

In order to collect information over large sea areas, our sensor nodes are spread widely on the sea, nearly covering all the oil tanker routes where oil spill accidents often occur. These sensors, following certain routing algorithm, eventually form a large acquisition network through self-organizing wireless sensor networks. Compared to Ad-hoc networks, WSN is a many-to-one network with lower power consumption and is able to withstand harsh environmental conditions, more suitable for operations at sea.

To reduce the cost, we have designed two types of nodes. One is equipped with GPRS module which can directly send the data back to the data base onshore. We call it the sink. The other type without the GPRS module mainly takes charge of data acquisition, and at the same time sending the data to the sink.

Since the location of the data acquisition buoys is fixed, it is easy for us to store the relevant information of the sink into other nodes. Then the normal node can transmit the data to the nearest sink according to the algorithm we designed beforehand. This data transfer method is quite similar to the simulated annealing algorithm, however, when comes to the annealing strategy, we emphasize particularly on the average flow of the entire network thus enable better balance of energy and load.

- **WSN Routing Algorithm**

On the design of the algorithm, we make some improvement on the existing GPRS protocol in order to achieve load balance. The major advantage of this protocol is that it does not need to store or maintain the routing table itself, in stead, it mainly makes choices of the routing according to the adjacent points, almost a stateless protocol. While choosing the route based on the minimum Euclidean distance, the transmission delay will be minimized; furthermore, as long as the network connectivity is under normal operation, it will certainly be able to find out a routing to the sink. In addition, in order to make up the deficiency of GPSR protocol in the routing cavity, we set the nodes in straight lines along both longitudinal and transverse direction so that make sure they can always find the target.

When certain node aims to transmit the data to the direction towards the sink, it will follow the dynamic algorithms below, as shown in the figure. X is the source node while D is the target sink.

Step 1: x sends broadcast packet to all the nodes within its effective range, and the nodes that receive the packet instantly send back information of their own position as well as the current loading "w", each time the data is retransmitted, the loading plus one.

Step 2: x works out the distance "d" between its adjacent node and the sink, and implement the loading "w" as offset, then make the node with maximum value according to the prediction function f(d, w) as the retransmit node. P (A) represents all the nodes that have received the package sent by x within the effective range while ε stands for the balance parameter between the distance and the loading.

$$f\left(d_i, w\right) = d_i + w \times \varepsilon, \qquad d_i < d_x, i \in P\{A\}$$

Step 3: x sends the data collected by the internal sensors to the chosen node, and pass on follow the same rules until it reaches D.

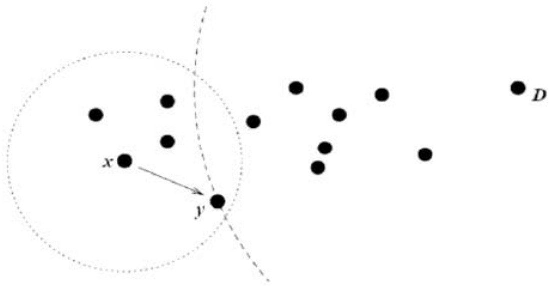


Figure 6 WSN Routing Algorithm

Distribution of Buoys

In that we implement WSN for data transmission, the distance among the nodes are greatly extended, due to our data transmission module, the effective transmission distance is able to reach more than 10 kilometers. However considering the effectiveness of the monitoring range, we narrow the distance between the adjacent sensors down to 8 kilometers and all the sensors are equally placed covering the oil transportation route offshore. Besides, we also put some buoys around the offshore drilling platforms within the monitoring area.

Figure 7 Distribution of Buoy

Brief Introduction of the Sensors

In our system, we mainly introduced following sensors: light sensor, viscosity sensor, infrared sensor, temperature sensor, wind speed sensor, wind direction sensor as well as air pressure sensor.

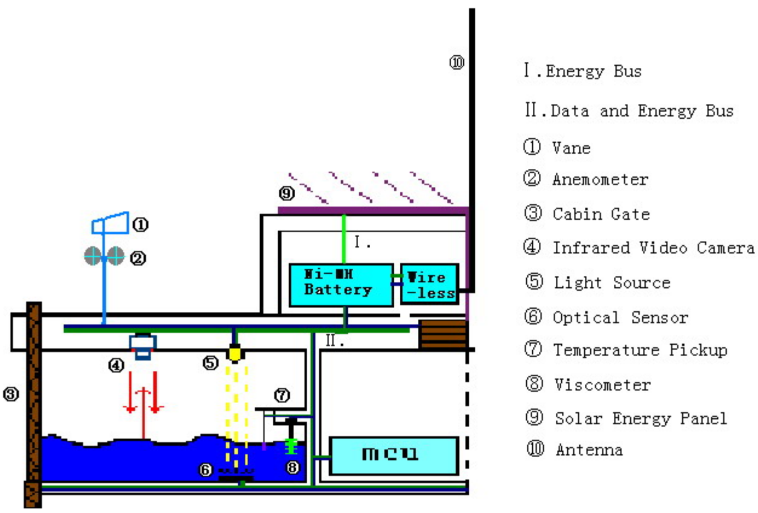


Figure 8 Sketch of Sensors Distribution

Infrared Image Processing Algorithm

In this section we firstly adopt the wavelet transform based on promotion proposed by Sweldens, which is also called second generation wavelet transform. It implements noise removing on the image through the Deslauriers-Dubuc interpolation filter in combine with the Euclidean algorithm. Then energy additive accumulation is implemented on the image after wavelet transform noise removing. Through N (N is a constant) times acquisition, we accumulate the energy of each corresponding pixel point gradually and then compare the result with that of the marine infrared photographs which are taken under the condition without oil spill. Through the comparison, we can get the available information of oil spill. Figure 10 shows the process of two images' processing described above.

Figure 9 Original Images -> Filtered Images -> Combined Image

- **Data Acquisition Related**

In the data acquisition part, we adopt two collecting methods. One is to sample at pre-set time intervals in accordance with the procedures. Taking the average power consumption cost of the equipment and actual speed of the oil spread into account, we set the time interval as 10 minutes timed by SCM built-in timer. The other data collecting method is manually acquisition under unexpected situation. After receiving of unexpected acquisition orders, it will immediately start data collecting, at the same time, re-reset the timers

Take the acquisition of transmittance for example; assuming the transmittance is represented by the radiation power transmitted to radiation power incident ratio, using the symbol T to express:

The values measured by the four cabins: T_1, T_2, T_3, T_4

$$E(T) = \frac{1}{4}\sum_{i=1}^{4} T_i \qquad (12) \qquad\qquad D(T) = \frac{1}{4}\sum_{i=1}^{4}(T_i - E(T))^2 \qquad (13)$$

If D (T) exceeds certain threshold, which means fluctuation of the data collected by the four cabins is large and the current situation is rather unstable. The system will automatically go into holding state, after waiting for certain period of time, restart collecting and calculate the value of D(T) to see whether to allow the system working under the normal state.

4.1.2 Data Processing Part

In the data processing part five functions are expected, including analysis of satellite remote sensing, real-time data analysis, resource scheduling analysis, prediction of the spread trend of spilled oil, and the expert analysis

- **Analysis of Satellite Remote Sensing**

Pictures of oil spill monitoring are regularly sent back to the processing center through marine remote sensing satellite everyday. Then, available information about oil spill will be extracted and added into the database for further use.

- **Analysis of Real-time Data**

In this section, data collected from the buoys will get further processing and analyzing in order to obtain useful information. Real-time data analysis will be given out together with a diagram based on the changing trend of the spilled oil which is concluded according to both historical and latest data. We think it a more convenient and direct way to offer the changing trend diagram rather than just deliver massive data to the users, especially who need to make resource scheduling at the time.

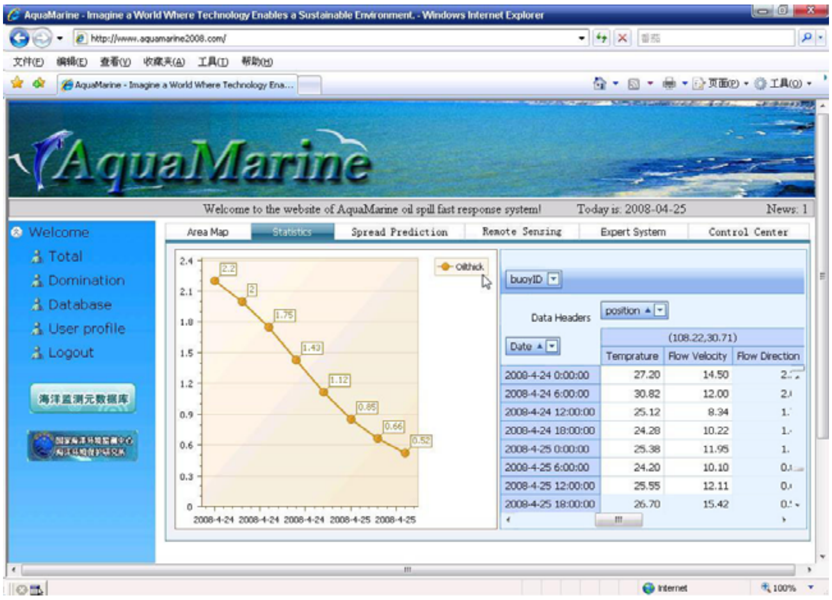


Figure 10 Analysis of Real-time Data

- **Analysis of Resource Scheduling**

In this section, we intend to present the rescue resources which can be deployed right at the time the oil spill occurs, furthermore, enable a better resource scheduling. The rescue resource may contain the number and position of crash boat, the location of the nearest rescue center, the contact way of the relevant people and the optimal route for rescue.

- **Analysis of Spread Trend of Spilled Oil**

In this section the data collected will be used as input for mathematical modeling. Then Lagrange tracking method [4] will be introduced to simulate the drift-diffusion of the oil film, meanwhile feedback is to be given to the users. As to this method, the oil film can be equivalent replaced by a large number of small oil droplets. The oil droplets spill into the water where oil spill accident occurs at certain rate, the drift rate of the droplets V_t is:

$$V_t = V + V' \quad (14)$$

In the equation, V and V' express the time uniform velocity and the fluctuating velocity of the droplets, where the time uniform velocity is mainly effected by wind speed and flow velocity. Under the precondition of less high accuracy, V' can be ignored. So we have

$$V_t \approx V \quad (15)$$

In each time step Δt, we can get the displacement ΔS of the droplet through V_t in the integration of time. When Δt is large, to meet the needs of precision, we can calculate the drift displacement of the droplet using the subinterval δt_k, thus during the time interval Δt, the displacement of the droplet is:

$$\Delta S = \sum^{k} V_{t,k} \delta t_k \quad (16)$$

$V_{t,k}$ is the droplet rate in δt_k, ΔS is the displacement of the droplet in Δt;

$$\sum^{k} \delta t_k = \Delta t ; \quad (17)$$

δt_k satisfies the following condition:

$$\delta t_k \le \left[\frac{u_k}{\Delta x} + \frac{v_k}{\Delta y} \right]^{-1} \quad (18)$$

In the equation above, u_k and v_k denote respectively the component of V_k in X-direction and Y-direction.

The migration velocity of the droplet in suspension layer equals to the average water velocity V_c, while the migration velocity V_s of the oil film is:

$$V_s = \alpha_\omega D \cdot V_\omega + \alpha_c V_c \quad (19)$$

Where V_ω stands for the wind speed on the sea surface; α_ω is the coefficient which reflects the influence on the motion of oil film caused by the wind, usually between 0.02~0.03; α_c is the ratio of the surface water velocity to the average water velocity, the value is 1.1~1.2; D is the conversion matrix of wind direction:

$$D = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \quad (20)$$

When $0 \le |V_\omega| \le 25m/s$, $\theta = 40^\circ - 8\sqrt{|V_\omega|}$; when $|V_\omega| > 25m/s$, $\theta = 0$。

By using software simulation, we can get the diffusion path and area graph based on mathematical modeling, and the result will be given accuracy test in Performance Analysis Part.

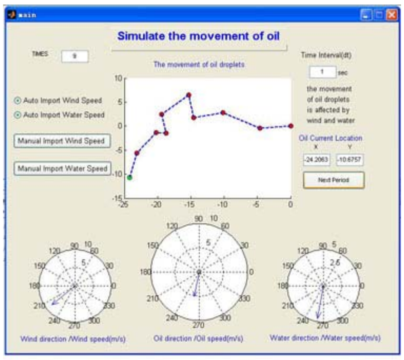


Figure 11 Matlab Simulation

- **Expert System**

Since our available data and analysis are categorized and all put into the data base connected with web sever. Experts from all over the world could log on our web set easily to get both historical and latest information, which enables them to offer solutions with pertinence. That is very practical especially when unexpected accident takes place while relevant people can not present on spot in the first time.

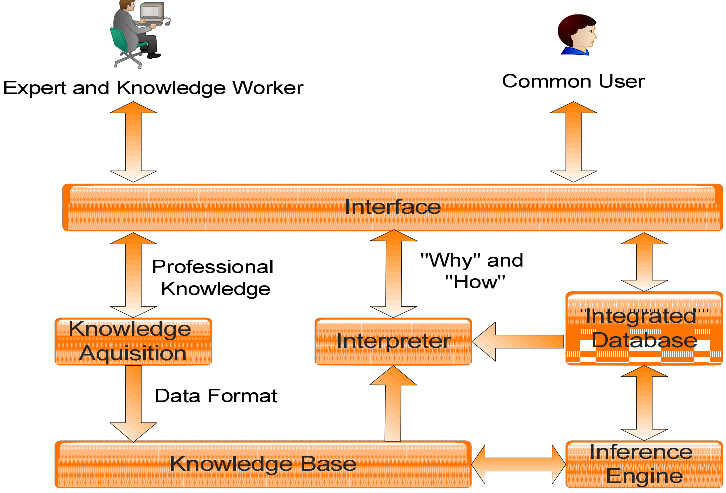


Figure 12 Expert System

4.1.3 Information Release Part

This part is to publish the information extracted from data processing part timely in visualized way. For users, the elementary way to get information is web visit, where a website is specially built. The users can log on the website, then get corresponding authority through identification. The users can be divided into three categories: normal users, advanced users, and administrators.

The qualification of normal users is just to browse the website. You can move the mouse to the location of a buoy. A window will jump out automatically from the website by means of script, which shows the fundamental hydrological information, such as temperature, wind speed, and the wind direction of the area.

The advanced users can be entitled with more rights of browse and territorial operation than normal subscribers. They can clip the buoy and get into the territorial operative interface. The interface is composed of five parts, which VIPs can clip the options to choose. They are “remote sensing image”, “data analysis”, “resource collocation”, “predictive analysis” and “expert system”, which are respectively focused on “satellite remote sensing analysis”, “real-time data analysis”, “resource scheduling analysis”, “spread trend analysis” and “expert system analysis”.

Figure 13 Interface of the System’s Website

The system’s administrators have the largest authority. They could change the configuration of the system and even revise some code of the system’s software part, along with the authority like advanced users. The main purpose of the large authority for administrators is to be convenient for updating and maintaining the system.

4.2 Software Overview

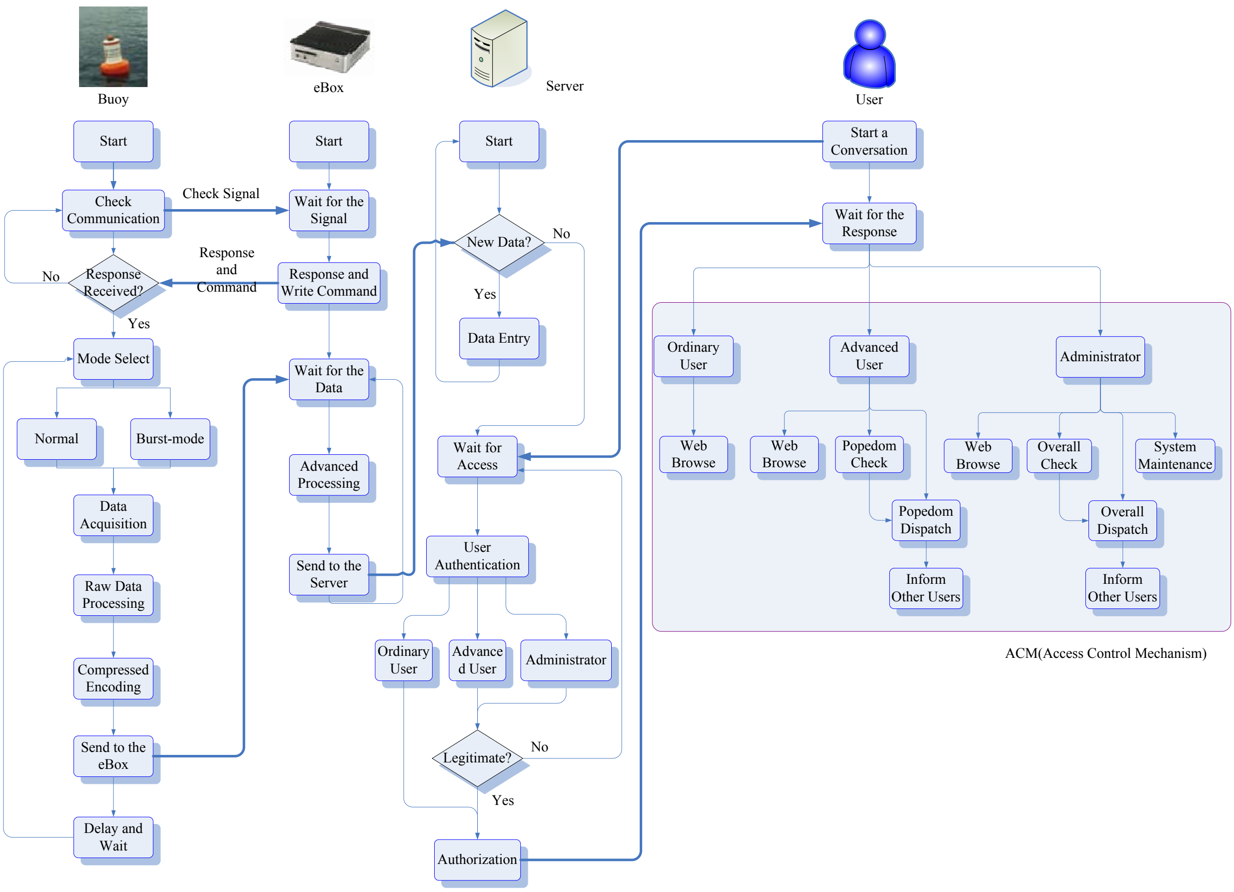


Figure 14 Function Overview

As indicated in the software function graphic above, our software application mainly contains buoy control, data processing by eBox as well as information release. In the buoy control part, we adopt ATmega128L MCU to control the data acquisition process, where the operating system is TinyOS [6], and the software development langue is nesC, meanwhile use cygwin [7] as platform for the development and ComTools to implement serial port debugging. Software of this part is mainly used for network routing searching. （4.1.1 WSN Routing Algorithm） and data balance calculating（4.1.1 Data Acquisition）.

As to eBox-4300, we adopt Win CE 6.0 as its operating system, and C # language for development on the platform Microsoft Visual Studio 2005, with .NET compact framework 2.0 as the class library. Software here has two major functions, data monitoring and processing. A server monitoring procedure will run on the eBox, moreover, a fixed port is developed to monitor the data flow from telecommunication lines and wait for the connection. Once data from the data acquisition part arrives, eBox will start data receiving procedures to receive the data. Besides, the code of the data processing will also be loaded into eBox, which on one hand enables analysis on the data packet according to data format, while on the other hand enables analysis on the data through mathematical modeling. (4.1.2 Oil Spill Prediction Analysis)

When comes to information release part, we adopt Microsoft Windows Server 2003 + IIS 6.0+Microsoft SQL Server 2005 as the operating system with Microsoft Visual Studio 2005 and Microsoft SQL Server 2005 as development tools. In this part, ASP.NET 2.0 (C#)+AJAX langue is put into service during the development. Software in this part takes charge of input of the data as well as early-warning publishing, including the input of the processed satellite remote sensing image（4.1.2 Analysis of Satellite Remote Sensing）, input of the unpacking data（4.1.2 Analysis of Real-time Data）, links of the database for resource scheduling（4.1.2 Analysis of Resource Scheduling） and analysis of the input data based on the expert system（4.1.2 Expert System）

4.3 Deployment Analysis

The deployment of the buoys, both anchor type and floating type, are shipped to the corresponding position set beforehand according to the latitude and longitude value. As to the anchor buoy, the fixing device should be put into service as well. After the connection of power supply module, the system will be able to start working and will send connectivity test signals to the base station onshore. During the course, an important point to mention is that since our buoys are mainly distributed along the transportation route, warning devices, such as caution lights with high penetrability are strongly suggested.

In order to optimize the system, eBox can be placed in the base stations onshore together with the information release system, which not only reduce the occupancy percentage of space, but also enable centralized management of the system components.

4.4 Testing Procedures

Out testing procedure mainly consists of software testing, hardware testing and entire system testing.

4.4.1 Software Test

In software testing part, we will accomplish basic function testing and software robustness testing.

- **Basic Function Testing for software**

In this section we mainly use the black-box testing to test the function of the entire software. During our testing course, we assume the entire software part a black box without opening. Taking none of the internal structure factors into consideration, we just implement our testing on the program interface. We input a group of normal historical data, then compare the result at output port with the historical results, to test whether the software part are normally operating.

- **Software Robustness Testing**

In this part of the testing, we have adopt white-box testing method to examine the robustness of the software, in order to minimize the software bug and take a look at the software operating situation under different extreme circumstances. We design the test case according to the structure of the internal procedures, test all the logic path of the procedure to identify whether the actual state is in line with the expectations. We first carry out static test on the software using artificial simulation technology and then input a group of pre-test data in accordance with certain criteria to get the procedures running in order to put up the dynamic test.

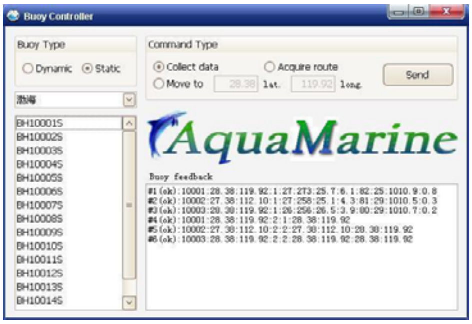
4.4.2 Hardware Test

As to the hardware testing, we introduce the FMEA (Failure Mode and Effects Analysis) model, which is widely applied in hardware testing project. FMEA is a monitoring method which can guarantee a reliable design. It is actually the combination of FMA (failure mode analysis) and FEA (fault impact analysis), used to give risk evaluation and analysis with the purpose of eliminating these risks or reducing them to acceptable levels and finally achieving optimum effectiveness. After basic indicators test, function test, fault-tolerance test (FIT) and long time running test, our system can work normally under common circumstances.

4.5 Performance Analysis

- **Buoy - eBox Test**

We mainly focus on integrated test in this section which will provide us with a better control of each module in the system. Buoy Controller, is a tool developed by us to carry out this test. We have gone through the function test, along with the connection test with this tool in this section. Based on what the Buoy Controller had displayed, our system passed the test of this part.



- **Matlab [8] Simulation Test**

In this part we mainly want to know the exact difference between the result predicted by our system and the actual result. In other words, we are testing the accuracy of the prediction by our system. Unable to conduct a real-time oil spill test in the sea, we had adopted a manual way to input historical data, by viewing the results of the forecast and the practical situation to evaluate our system's performance in oil spread prediction part. We chose one accident occurred in Bohai Bay in June, 1990 as our test case. After it happened, China Marine Environment Monitoring Center had sent meteorological aircraft to conduct inspections on this area. We simply input the data collected by the aircraft and got the 12 hours spread prediction results shown in Figure xx by matlab simulation. In fact, we can get the prediction result in different time by just simply dragging the slide block in the TIMES part. We compared this prediction about area spread and the prediction concerning on route spread in section 5.1.2 with the actual oil spread situation, finding that our prediction has a high degree of accuracy up to 90 percent when judging whether there exists an oil spill accident or not, which can fully meet the requirement of practical application.

Spill Location	38° 32'48" N 120° 56'42" E
Temperature (℃)	10
Spill Volume (m^3)	300
Wind Velocity	0～192h, 3.0 m • s^{-1} from SSW
Oil Type	Heavy fuel oil type No.2
Oil Viscosity (m^2 • s^{-1})	$v_0 = 8.6 \times 10^{-4}$
Buoyant Velocity	v_b = 0.00254 m • s^{-1}

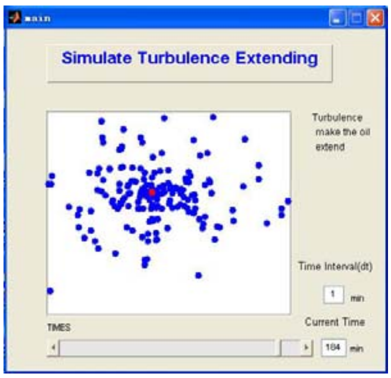


Figure 16 Matlab Simulation

5. Embedded Analysis

5.1 Embedded Image

In order to ensure the operation on eBox-4300, we adopt our specially designed Windows CE 6.0 image. The development tools include Microsoft Visual Studio 2005, Platform Builder with WinCE6.0 R2, and ICOP_eBox4300_60CS: X86 as BSP. The main components are as follows

- .NET Compact Framework 2.0 .NET provides a lot of encapsulation class for application software development, since the development langue on eBox-4300 is mainly C#, thus the NET is required.
- **CAB File Installer/Uninstaller** enables installer/ uninstaller of application program on eBox-430
- **Firewall, Network Bridging, TCP/IP, Network Utilities, Winsock Support, Wired Local Area Network, Wireless LAN** according to the system functional definition, eBox-4300 is in application of communication between buoys and networks as well as the data transmission among database, so this component is necessary;
- **Remote Desktop Protocol** enhanced RDP6.0 offers better support for Display， higher communication security，connection with eBox-4300 through multi-terminal as well as real-time monitoring；
- **Authentication Services(SSPI)** foundation of the system security, providing authentication function for remote connection ;
- **Hive-based Registry** used to keep a record of the parameters in the storage device, thus ensure a quick recovery after restarting.
- **ROM-only File System** protect the data security through power-fail protection
- **Serial Port Support & USB Host Support** support the communication between eBox-4300 and peripheral equipment through serial port or USB.

Based on these choices, we finally constructed a micro-WinCE 6.0 Image. EBox-4300 based on the image can well meet all our needs with good system response. As the data processing platform and control center of the marine oil spill monitoring system, we have tried our best to maximize the redundancy of the system on eBox-4300. We also take some measures to ensure the system security and recovery of system failure, such as the use of ROM-only File System and Hive-based Registry to protect the important data. Considering that, in practical application, the system can also extend with some alarm devices, so we still add the serial port and USB support to this system.

5.2 Embedded Software Design

Embedded Software consists of two parts: the part works in eBox-4300 is the core of the entire system which we use C # to develop. The other part is applied in the MCU of the sea buoys using the existing TinyOS as the operating system, where nesC is adopted to realize the system functions.

Software works in eBox include: receiver software for data collected, which adopts Socket in the .Net Framework in order to receive GPRS data through the Internet; software for marine parameters analysis with two modules, one is used for processing the current data, and the other for forecasting the oil spread trend based on the algorithm extracted from mathematical modeling.

All the procedures implemented in eBox-4300 are background executing, while all the foregrounds are presented to the users through the WEB. That is to say, as long as the receiver can get to the Internet and have a new version of IE browser, it can easily get access to our system, which is very flexible.

5.3 Embedded Component

As the handling capacity of embedded devices is growing rapidly, it is possible for them to completely replace the PC under many occasions. On the other hand, embedded devices usually have higher degree of integration with smaller volume, which are more suitable to withstand the harsh working environment in industry.

Sensor nodes serve as the perception part of our system. They have formed a large network on the sea surface. Each of the nodes is equipped with the following modules: sensing module, processing unit (MCU), data transmission modules and power supply module.

As to the buoys placed on the sea, the problem of power consumption should be paid more attention. Although we have introduced solar power generation system and Ni-MH Batteries, the energy collected from solar power in the daytime is very precious, so our adopting of the embedded system in replace of the PC equipment is more suitable in this case. The embedded devices we use will automatically go to dormant state when there is no acquisition order, and be awakened at sampling time.

In addition, we have a large number of sea sensor nodes, and thus we must reduce the spending of each node to maintain our cost. Compared with the previous systems, the high efficiency and low cost of our embedded equipment are both our advantages which ordinary PC can not achieve.

6. Project Status

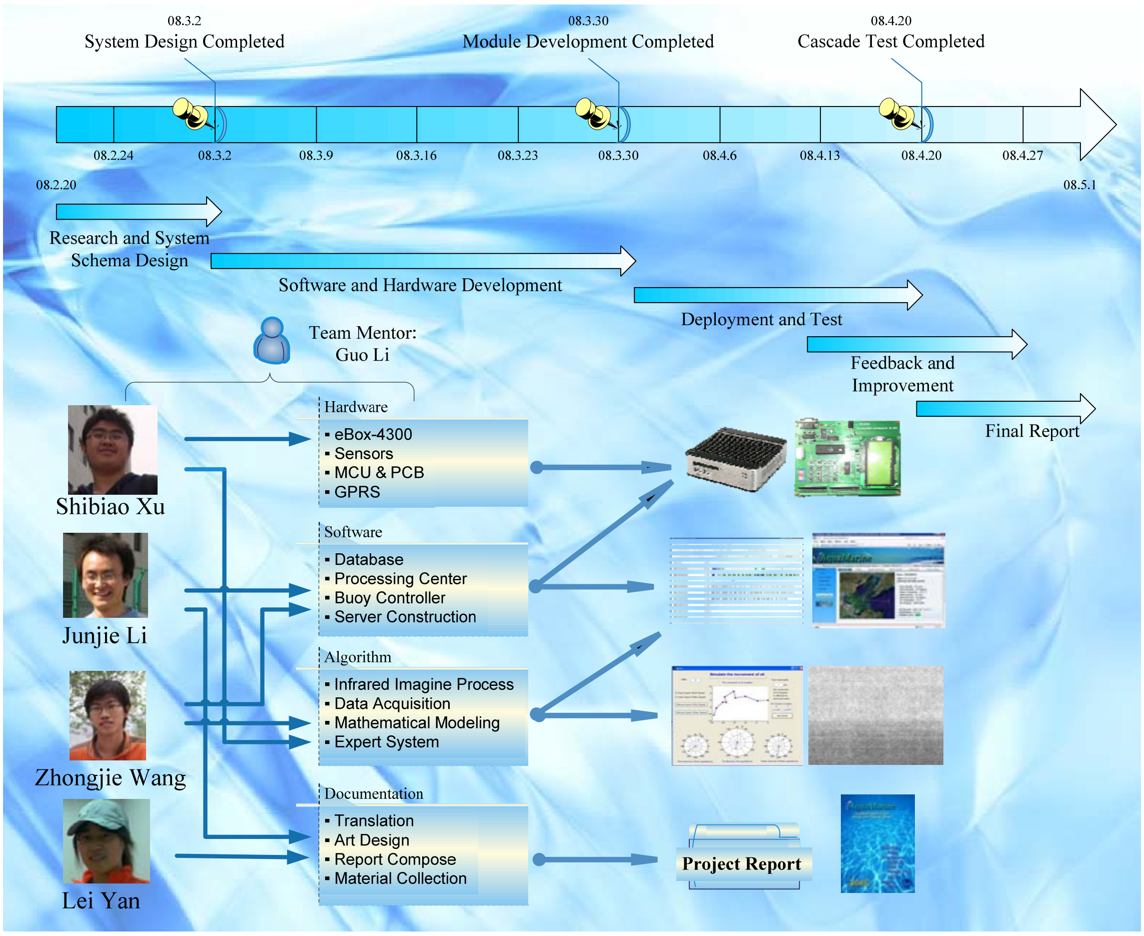


Figure 17 Project Status

7. Conclusions

The theme of this Imagine Cup is about "environment" and the marine environment receives more and more attention from people. Solutions to the marine environment pollution have been long expected.

Therefore, among numerous pollution of the marine environment, we designed a real-time monitoring and pre-warning system for oil spill pollution. In the design process, we referred to a great deal of information and visited many relevant units. In order to have a comprehensive and profound understanding of the marine oil spill, we specifically visited the China University of Petroleum many times, and had a number of talks with some professors in relevant field.

We also came to the China State Oceanic Administration, talking with the relevant researcher for long time with the purpose of better understanding of the sea buoys and marine monitoring system.

In order to have a precise estimate of the system cost and market demand, we designed survey program and market investigation. In this process, we start from scratch, from completely unfamiliar to in-depth proficiency, from asking others for help to independent thinking and solving the problem.

We realized our system little by little, and make improvement all the time. In the process, we learned not only how to make AquaMarine system, but also the general processes of systems development and the way to solve practical problems. More importantly, we learned how to innovate, how to imagine and how to build a bridge between reality and the ideal.

In the process of going through our project, we also come into contact with a lot of front technology, such as WSN network, Windows CE 6.0 embedded development platform as well as mathematical modeling based on the oil spread. In fact, for each part, there are various options available, after a great deal of information collected and all the comparisons, we gradually find each part the best solution, and eventually formed our AquaMarine. What we hope is that we want to use technology to make sustainable environment possible, let technology become the helper to protect the environment rather than the killer.

During our system's development process, we are also fully aware of the importance of the teamwork. A reasonable and clear task division is necessary for system development .Only by the effort of each member to well perform their respective duties as well as fully confident in the teammates can ensure a excellent development process and the accomplishment within the required time.

In short, in this competition, we pay a lot while we harvest more. Of course, we hope deeply that our system can be applied in practice. We hope it to make its own contribution to the monitoring the elimination of the marine oil spill as well as to the sustainable environment. At last，we want to express our thanks to our sponsor Guo Li, who give us a lot of valuable suggestions.

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